Operational Evaluation of a Passive Beef Cattle Feedlot Runoff Control and Treatment System

B. L. Woodbury, J. A. Nienaber, R. A. Eigenberg

Abstract. *Nutrients from feedlot runoff can infiltrate beneath long–term storage ponds. Pond embankments' wetting and drying cycles facilitate infiltration paths as does weed growth that form roots channels. The research objectives were to construct and evaluate a passive runoff control system to reduce or eliminate long–term liquid storage. Runoff volumes, nutrient totals, and peak discharge were estimated using the Nutrient Fate Model for Beef Cattle Feedlots (Eigenberg et al., 1995). A vegetative filter strip was sized based on these estimated values. A flat–bottom terrace was constructed to collect runoff, provide temporary liquid storage, and accumulate settable solids, while distributing the nutrient laden liquid fraction uniformly across a vegetative filter strip. No runoff from the vegetative filter strip was recorded during the study period that lasted from 1999 through 2001, indicating that the basin discharge was effectively utilized for grass production. The volume of water remaining in the basin that was available for deep infiltration was greatly reduced when compared to traditional long–term runoff storage systems. This reduction was evident as the solids storage system began to accumulate solids, thereby reducing the total liquid storage volume of the basin. The passive beef cattle feedlot runoff treatment system appeared to be an improvement to traditional storage systems.*

Keywords. *Animal waste management, Feedlot runoff control, Nutrient management, Waste treatment.*

Abbreviations. Antecedent soil moisture condition (AMC), electrical conductivity (EC), electromagnetic induction (EMI), mean hydraulic retention time (HRT), poly vinyl chloride (PVC), power take–off (PTO), vegetative filter strip (VFS).

Recent public attention has been focused on nutrient pollution of surface and groundwater, and as a result beef cattle feedlots have come under increased scrutiny. There are several factors within the runoff control system that require attention to minimize nutrient pollution of the environment (McCullough et al., 1999).

Seepage from waste storage lagoons has been the subject of investigations since the early 1970's. Laboratory and field–scale studies examined the seepage rate from lagoons under varying environmental and climatic conditions (Huffman and Westerman, 1995; Miller et al., 1985; Ritter et al., 1984; Rowsell et al., 1985). As a result of these studies, it was concluded that initial seepage rates can be high, but physical and chemical "sealing" of the lagoon bottoms increased with time, effectively sealing the lagoon.

Parker et al. (1999) demonstrated that sidewall discharge accounted for most of storage pond seepage. Much of the seepage resulted from wetting and drying cycles on the sidewalls of the ponds. The sidewalls support vegetative growth forming root channels that facilitate deep infiltration and seepage from the earthen storage facility. Sidewall seepage has been estimated to account for 50 and 70% of the total seepage volume (Parker et al., 1999).

Estimating the negative environmental impact seepage has on groundwater quality is complicated by physical and chemical non–equilibrium contaminant transport of most groundwater aquifers. Westerman et al. (1995) evaluated seepage from two anaerobic lagoons constructed on a sandy, coastal plain soil. They concluded that accurate determination of the environmental impacts from lagoon seepage was complicated by difficulty in obtaining information on the hydraulic domain and also by factors affecting contaminant transformation and transport. These uncertainties complicate risk assessments of these systems. One solution could be to construct near–impermeable pond liners from compacted clay or geomembranes. However, these structures may also fail over time. Another possible solution is to develop a system that eliminates long–term storage of liquids and provides treatment of the nutrient laden effluent. This system would minimize negative environmental risks to surface and groundwater by limiting deep infiltration of nutrients.

The objectives of this research were to design, construct, and evaluate a passive runoff control system to reduce the volume of long–term liquid storage, provide adequate solids separation, and evenly distribute the liquid basin discharge water for grass hay production.

Material and Methods

A portion of the Meat Animal Research Center (Clay Center, Nebr.) feedlot was selected because it was not serviced by any runoff control system. Eight pens, approxi-

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Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

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mately 30 × 90 m each, with a 4% slope from the feed bunk were stocked with 70 to 80 head of finish cattle for approximately 180–day cycles. Each pen had a center mound, 3–m wide concrete pad behind the bunk with approximately 0.36–m bunk space per head. Typical pen maintenance included surface scraping and reshaping the center mound following removal of cattle at the end of each cycle. Prior to construction, runoff from the pens accumulated down gradient from the feedlot. Preliminary soil core analysis indicated no buildup of phosphorus or nitrate beyond 120–m down gradient from the feedlot. However, two sample points up gradient of the 120–m site contained significant amounts of phosphorus in the surface horizon and elevated nitrate levels to a depth of 1.8 m (unpublished data). These cores were collected from an area that had been part of an abandoned, sparsely populated feedlot and may have been affected by this previous operation.

System Design and Construction

The runoff control system design components consisted of a grass approach, a terrace with a flat–bottom debris basin, and a vegetative filter strip (VFS). Runoff nutrient totals from the pens were estimated using the Nutrient Fate Model for Beef Cattle Feedlots (Eigenberg et al., 1995). The model used the number of head and an average size of cattle for all seasons to estimate nutrient runoff from this facility. The vegetative filter strip was sized based on the estimated volume and nutrient load in the runoff. Additional design criteria required operation and maintenance of the system using equipment typically found on confined beef cattle feeding operations.

A flat–bottom debris basin with a terrace was designed to collect runoff, provide temporary liquid storage, and accumulate settable solids, while dispersing the liquid uniformly across the vegetative filter strip. Maintenance of the debris basin was designed to use a front–end loader for solids removal. Using a NRCS runoff curve number of 85 (Antecedent Soil Moisture Conditions AMC = II) to represent the feedlot surface, it was estimated that 88 mm of runoff would result from a 25–year 24–hour design storm of 127.0 mm of rain. Using a runoff curve number of 58 (Antecedent Soil Moisture Conditions AMC = II) for the contributing grass area outside the feedlot, it was expected that 30 mm of runoff would result from the design storm.

It was estimated that peak discharge from the pen surface resulting from the design storm would be 0.9 $m^3 s^{-1}$. This discharge was estimated using the 25–year 24–hour design storm, 24,000 m^2 surface area, rainfall type II, with a time of concentration of 0.11 hours and a curve number of 85. Also, it was determined that a 0.30–m debris basin would be needed for settable solids storage. Using these values, a mean hydraulic retention time (HRT) during this peak discharge would be approximately 5 to 8 min. However, this HRT would depend on the level of stored solids reducing the effective volume of the basin. Typical HRTs for similar grit removal basins designed for municipal systems are between 45 and 90 s (Metcalf and Eddy, 1991). It was expected that under the worse case scenario of the design storm, the basin would provide adequate solid separation of settleable solids.

The debris basin and terrace were constructed to maximize the vegetative filter strip down–gradient length and minimize the distance from the feedlot to the collection basin. An elevation isoline was selected that provided the needed cut–to–fill ratio for terrace construction. In addition, allowances were made to provide a minimum 1% slope gradient for debris basin discharge and prevent backup of liquid within pens except when design capacity was exceeded. The area topography necessitated a 10° angle from the feedlot fenceline to the terrace (fig. 1). It added an additional 1.2 ha of grassland runoff to be co–mingled with the feedlot runoff. The debris basin was designed with a 3–m wide base to accommodate cleaning equipment. The terrace was constructed with 3:1 slopes, while clean–out access was facilitated by a 6:1 slope entry (fig. 2).

Total debris basin and terrace length was 300 m. Thirteen 20–cm Ultra Rib PVC storm discharge pipes were installed through the terrace at 21–m intervals and at an elevation that provided 0.3 m of solids storage (fig. 2). Five 20–cm clean–out lines were installed at basin level to completely drain the basin prior to solids removal (fig. 2). Discharge pipe elevations were established by excavating a 1–m deep hole at the inlet end of the pipe, then installing a 1.2–m long 13–mm rebar with attached bolt to the predetermined elevation (fig. 3). With the rebar in place, the hole was filled with concrete to the design elevation. Next a 0.3–m trench was excavated and the discharge pipe was installed and attached to the concrete column ensuring equal elevation for all discharge pipes. The trenches were backfilled and the 25–mm ribs on the exterior of the drainline provided strength and a barrier to sidewall seepage. The 6.0–ha bromegrass VFS extended the length of the basin and ranged from 200 to 210 m in width perpendicular to the terrace at a slope of approximately 0.5%.

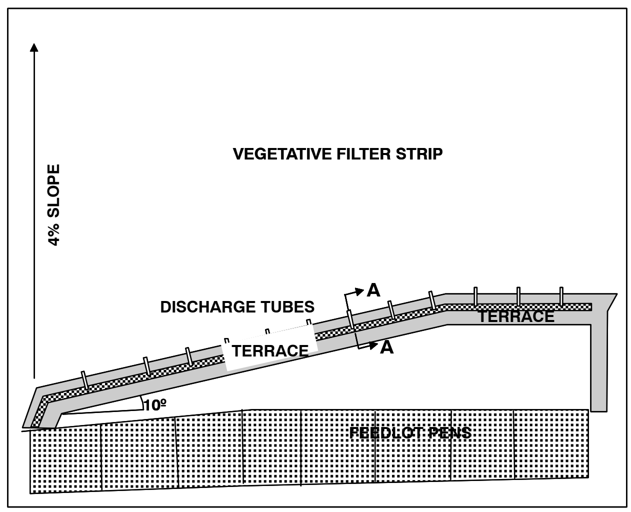

Figure 1. Diagram showing the relationship of the feedlot pens, debris basin with terrace, discharge tubes, and the vegetative filter strips.

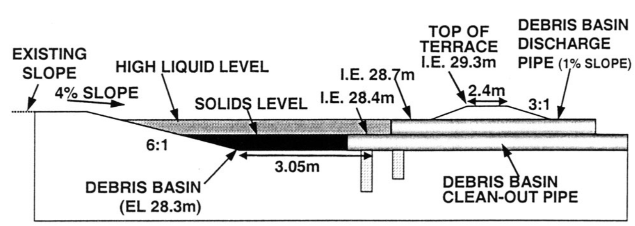

Figure 2. Schematic cross–sectional diagram (A–A in fig. 1) of the debris basin, terrace, discharge tubes, and drain tubes.

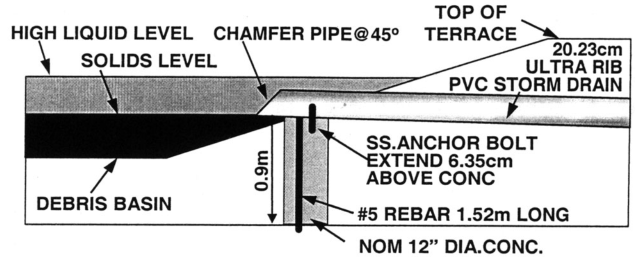

Figure 3. Schematic cross–sectional diagram of the elevation support column and the discharge tube.

Instrumentation

During the summer of 1999, four sampler/flowmeters were installed to evaluate runoff system performance (fig. 4). Two separate sets of berms were established to co–mingle and direct runoff from two adjacent pens through one of two 0.23–m Parshall flumes (fig. 4). A sampler/flowmeter (ISCO portable sampler model 3700 with model 3220 flow meter) was installed at each flume for use in characterizing (100–mL samples, 15–min sample interval, four samples per container) runoff water quality. Two additional 15–cm Parshall flumes were installed down gradient from the basin discharge tubes. Samplers (ISCO portable sampler model 6700 with model 730 flow module) were also installed at each flume to collect terrace discharge water. The sampling protocol was the same as described earlier.

Berms were constructed along the sides and the down–gradient end of the VFS to isolate it from the surrounding environment (fig. 4). A portion of the VFS was divided with a berm such that the runoff from the four pens was isolated from the rest of the VFS (fig. 4). At the down–gradient end of this isolated section, a 0.15–m Parshall flume was installed and instrumented with a stage recorder to measure VFS runoff (fig. 4).

Four transects were established within this isolated portion of the vegetative filter strip (fig. 4). Porous ceramic cups were installed to sample water infiltrating below the VFS root zone. Transects 1 to 3 were placed in naturally occurring flow paths. A series of six ceramic cups were placed in a circular arrangement at the up–gradient and down–gradient of these flow paths. The cups were positioned in a 1–m radius and extended 1.5 m below the soil surface. The radius of cups was connected with a common 6.4–mm copper line such that one vacuum source could be used for all six cups. Transect 4 was placed along a naturally occurring ridge that did not receive any basin discharge. Placement of all cups was facilitated by the use of electromagnetic induction mapping coupled with a global positioning system further described in Eigenberg and Nienaber (1998) (fig. 5). The assumption was that relatively high soil electrical conductivities from accumulated salts indicated soil that had received large volumes of nutrient–laden feedlot runoff (fig. 5). It was expected that soil water samples would be periodically collected and analyzed. However, there has been no extractable soil water to date.

During the summer months when precipitation events were less frequent, the debris basin liquid was drained using the five clean–out lines. It was accomplished by removing the rubber seals covering the inlet end of the lines and allowing the liquid to drain through the terrace to the VFS. Once the liquid had been decanted, the solids in the debris basin were allowed to dry until they were firm enough to be removed with a front–end loader. Multiple samples of the solids were taken and commingled during the removal process. Basin solids were analyzed for total and volatile solids, total and organic nitrogen and total phosphorus during the 1999 through 2001 season.

Results and Discussion

System Operation

Solids were successfully removed from the basin during the summers of 1997 through 2001. The total mass of dry solids deposited varied from a high of 98,000 kg for year 1999

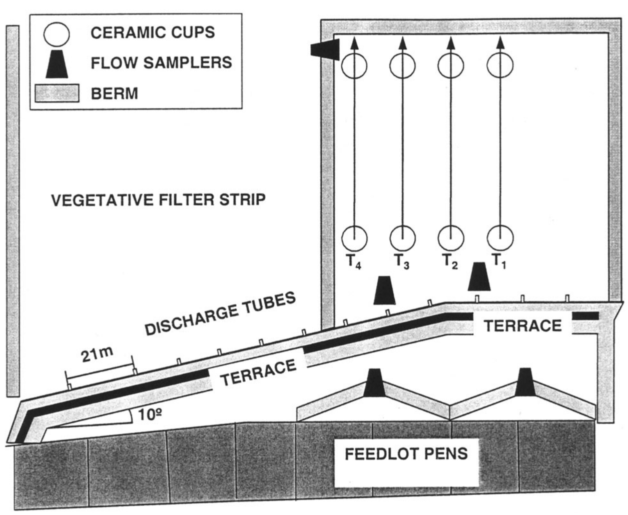

Figure 4. Diagram showing the relationship of the feedlot pens, debris basin with terrace, discharge tubes, and the vegetative filter strips (not to scale). Note the addition of the flow samplers, ceramic cups, and berms for isolation of the instrumented section of the vegetative filter strip. Transects are denoted as $T_1 – T_4$.

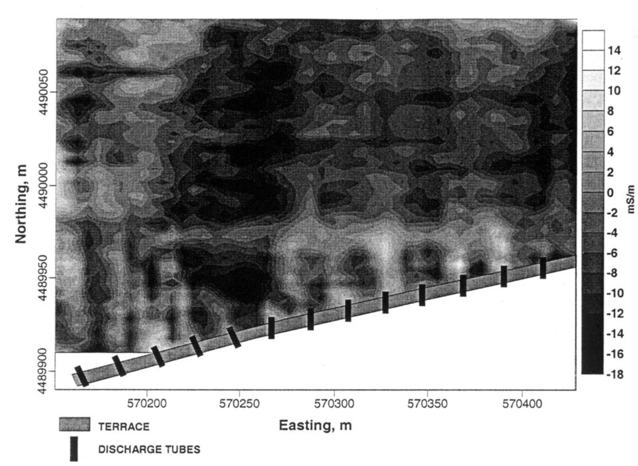

Figure 5. Electromagnetic induction (EMI) map of the vegetative filter strip with the position of the terrace and discharge tubes over–laid for reference. The EMI map has been adjusted to show changes in bulk soil electrical conductivities from the summer of 1997 to the summer of 2001. Note that lighter shaded areas indicate a net increase in apparent soil electrical conductivity and darker shaded areas indicate a net decrease in apparent soil electrical conductivity.

Table 1. Chemical and physical composition of solids removed from basin.[a] [b]

Year	Total Solids (dry) (kg)	Volatile Solids (kg)	Total Nitrogen (kg)	Organic Nitrogen (kg)	Total Phosphorus (kg)	Hay Crop Dry Matter (kg)
1997	67,000	NA	NA	NA	NA	NA
1998	49,500	NA	NA	NA	NA	NA
1999	98,000	14,500	450	380	170	NA
2000	37,100	5,900	180	150	75	32,760
2001	54,400	9,400	310	280	105	25,100

[a] The basin area was approximately 900 m^2.
[b] Pen surface area contributing to runoff is approximately 24,000 m^2.

to a low of 37,100 for the following year (table 1). Approximately 14 to 17% of solids deposited in the debris basin were volatile with an average nitrogen to phosphorus ratio of 2.7 to 1. Most of the nitrogen deposited in the basin was in the organic form.

Problems were encountered in measuring flow through the Parshall flumes, particularly at lower flow rates. The problem stems from not meeting the minimum flow requirement of the flumes during these periods. Additional difficulty was experienced in accurately measuring the upstream level with pressure transducers during these low flow periods. Therefore, estimations of the runoff volumes were based on the NRCS curve number method. Average total suspended solid concentrations of the runoff water entering and exiting the basin were determined from collected samples. Solids deposited in the basin were estimated by multiplying predicted runoff (m^3) by average TSS (kg m^{-3}) for runoff and basin discharge. It was assumed that the quantity of runoff entering the basin was the same as the basin discharge because liquid level remained near the base of the discharge pipe during operation. Total TSS (kg) was then adjusted for discharge TSS (kg) resulting in an estimated 30,670 and 41,680 kg for the 2000 and 2001 seasons, respectively (table 2). These approximations were surprisingly close to

Table 2. Predicted runoff, basin discharge, and total solids from measured rainfall events.

Date	Rain Fall (mm)	Predicted[a] Runoff (m^3)	Avg. TSS Runoff (kg m^{-3})	Avg. TSS[b] Basin Discharge (kg m^{-3})	TSS Runoff (kg)	TSS Basin Discharge (kg)
4/17/2000	16	56	0.40	0	20	0
5/26/2000	38	300	0.20	0	60	0
6/12/2000	30	180	1.77	0	320	0
6/20/2000	56	676	10.28	1.56	6,920	1,050
6/26/2000	53	610	17.28	1.89	10,540	1,150
7/05/2000	100	1,825	9.09	2.39	16,590	4,360
8/19/2000	41	354	8.37	0.51	2,960	180
				Total	37,410	6,740
5/04/2001	69	992	17.36	1.50	17,220	1,490
5/29/2001	63	828	14.07	0.50	11,650	410
5/30/2001	46	883[c]	15.30	1.38	13,510	1,220
6/04/2001	20	200[c]	12.10	0	2,420	0
				Total	44,800	3,120

[a] Values determined using NRCS curve number 85 for pen surfaces and 58 for grass surface assuming AMC II.
[b] Zero values indicate no measured discharge volume.
[c] Values determined using NRCS curve number 93 for pen surfaces and 76 for grass surfaces assuming AMC III.

the actual values removed, considering the unrecorded runoff during the winter months when instruments were not in place (table 1).

To evaluate discharge water distribution, electrical conductivity (EC) maps of the VFS were determined non–intrusively using electromagnetic induction mapping (EMI). It was also assumed that the discharge water carrying dissolved salts would accumulate in areas receiving greater loads. It was expected that this loading would be reflected in the soil bulk EC. Visual inspection of figure 5 indicates greater EC values near the basin discharge. However, the relative increase appears to be distributed across the entire length of the basin. The distance into the VFS from the basin discharge due to salt loading could be related to the volume and duration of the runoff event. This zone may require additional monitoring to prevent excess salt accumulation limiting the effectiveness of the VFS.

System Maintenance

Operational problems were experienced when portions of the feedlot isolated for measurement experienced crossover flow between pens. Consequently, greater solids deposition was located on one end of the basin. Earthen berms were established between the pens to limit crossover flow; however, erosion and animal traffic limited the long–term effectiveness of the berms and uneven solids deposition persisted within the basin. Wooden planks were placed at ground level between pens to limit crossover flow. Also, periodic removal of soil deposited under the bottom cable of the down–gradient fence was needed to ensure adequate water drainage out of each pen. During the 2000 season, the solids were more evenly distributed along the entire length of the settling basin.

Additional operational problems were experienced with the establishment of bromegrass in the VFS. Broadleaf and grassy weed problems resulted in poor bromegrass establishment in the field. Consequently, bromegrass was replanted and an acceptable stand was established during the 2000 season.

Basin solids were removed on an annual basis during late summer (August or early September). During this period, high ambient temperatures and relatively little rainfall is typical. This weather was generally ideal for drying the retained solids once the basin water had been drained via the clean–out tubes. A front–end loader was used to remove the solids by working laterally along the basin. The solids were loaded onto a manure spreader and applied to a field. Most of the basin bottom was sufficiently firm and dry providing a tractable base for the loader. However, wheel ruts were created in areas of the basin that were not sufficiently dried. Following solids removal, the basin was allowed to dry before the ruts were repaired. Repair of the basin following solids removal was considered only a minor maintenance issue and did not require any special equipment.

The brome grass hay was harvested once or twice annually depending on the timing and volume of rain received during the growing season (table 1). The hay was cut and baled using typical hay harvesting equipment. The grass approach to the basin was mowed periodically using a tractor mounted, PTO mower. The diversion berms directing the runoff from the two sets of adjacent pens were mowed using a handheld, gasoline–powered string mower. The grass approach, debris basin terrace, and brome grass hay field were sprayed periodically for broadleaf weed control.

Conclusions

The passive feedlot runoff water control system demonstrated very good solids separation, with minimal time required for operation and maintenance. Annual removal of solids collected in the basin was accomplished using a front–end loader and a manure spreader. The time required for annual removal of the solids and repair of the basin bottom from loader traffic was less than 8 hours. Both processes were accomplished with the front–end loader. Additional maintenance included periodic removal of the soil berm developed along the down–gradient fenceline of the pen. Two processes formed this berm. As the animals walked along the down–gradient fenceline, wet soil was forced outside the pen where there was no animal traffic. The second process resulted from sediment deposition as the runoff flowed from the pen surface to the grass approach of the basin. This berm would impede the flow of water off the pen into the control system and promote cross–pen flow. Also, periodic mowing of the grass on the terrace and along the basin approach was required for grass and weed control.

More than 80% of the suspended solids were removed from the runoff water as it passed through the system. Additionally, no water was measured leaving the VFS. Soil moisture conditions were not sufficient to extract water with the ceramic cups placed in the drainage flow lines. This low soil moisture condition would indicate that the effluent water was effectively used for grass production.

The volume of water remaining in the basin for deep infiltration was greatly reduced when compared to traditional long–term runoff storage systems. This was particularly evident as the passive runoff control system began to accumulate solids, thereby further reducing the effective liquid storage volume. The area of the basin with the solids accumulation was firm and tractable for late summer solids removal; however, during a wet year, solids removal may be delayed. To allow for this possibility, the basin approach slope could be reduced to allow for solids removal with a rear mounted box scraper on a typical farm tractor. The box scraper could pull the solids up on the basin approach slope for removal with the front–end loader. This operation would eliminate the need for the equipment to be operated directly in the basin.

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